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*Published in:*  
Radiation Regulator

*Publication date:*  
2015

*Document Version*  
Publisher's PDF, also known as Version of record

[Link back to DTU Orbit](#)

*Citation (APA):*  
Andgren, K., Andersson, K. G., Magnússon, S. M., & Physant, F. (2015). New and recently finalised activities within the NKS Programmes for Nordic cooperation on nuclear reactor safety and emergency preparedness. *Radiation Regulator*, 2(1), 24-32.

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# **Radiation Regulator**

**The International Journal  
Supporting Continuous  
Professional Development**

ISSN 2052-4846

**Volume 2, Number 1**



# Research



## New and recently finalised activities within the NKS Programmes for Nordic cooperation on nuclear reactor safety and emergency preparedness

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Received 27 February 2014; Accepted for publication 8 May 2014

### ABSTRACT

Over the years, NKS has provided funding for hundreds of research activities in fields comprising reactor safety, decommissioning, nuclear and radiological emergency preparedness, and management of radioactive waste. Advanced technologies and methods developed under the NKS framework have been used within the Nordic countries as well as internationally. Two programme areas are defined under the NKS platform: The NKS-R programme on nuclear reactor safety and the NKS-B programme on emergency preparedness. Three articles, giving an introduction to NKS and its two programmes, were published in Radiation Regulator in 2013. This paper is aimed at providing a total overview of the NKS activities that ran in 2013 and 2014.

### Introduction

After the annual call for proposals for new activities, members of the NKS board evaluate the proposals with respect to how well they meet the key objectives of NKS. Among these key objectives are: To maintain and strengthen Nordic competence, to develop Nordic cooperation, and to support work, which is relevant to Nordic authorities, organisations, industries and university departments. A funding decision for one year is then made at a board meeting in the beginning of each year. Although more than one million euros was available for NKS to support activities in 2014, this year's decision was unusually difficult because of the large number of high quality proposals. Many NKS activities running in 2013 have been concluded, and all final activity reports are available cost-free on the NKS website. A number of the activity consortia

from 2013 requested and received funding from NKS for additional studies in 2014 with an expanded scope, and also a number of completely new activities commenced in 2014. This paper gives short descriptions of each of these activities. To view any reports, see: [http://www.nks.org/en/nks\\_reports/](http://www.nks.org/en/nks_reports/)

### NKS-B activities in 2013/2014

Only one of the NKS-B activities in 2014 was a continuation from 2013. No activities related to management of radioactive waste and discharges have been carried out in the latest few years. Brief descriptions of the activities are given below under the headings of the four different research areas of NKS-B:

- *Emergency Preparedness*
- *Measurement Strategies, Technologies and Quality Assurance*



- *Radioecological Assessments*
- *Management of Radioactive Waste and Discharges*

## *Emergency Preparedness*

### EMSEM

Nordic cooperation on emergency preparedness issues is useful on many levels, e.g., in developing and conducting exercises and sharing results from national exercises, especially where specific issues of common relevance to Nordic areas are examined. A main task for the EMSEM activity, which ran in 2013, was to address the results of Nordic participation in the recent large Swedish REFOX exercise, and facilitate inter-Nordic cooperation to derive learning points. This was accomplished through the arrangement of a seminar held in Stockholm in August 2013. Seminar sessions included presentations of results from a range of different REFOX exercise scenarios (e.g., airborne search for sources in the environment, suspected dirty bomb area examination, fallout measurements), as well as group discussions on ideas for future improvement of Nordic emergency preparedness, also taking into account results of other recent Nordic exercises.

### MOBELRAD

Mobile measurement capacity is an important resource in mapping and addressing widespread contamination scenarios following a nuclear power plant accident or radiological incident. The provision of mobile measurement assets to other countries is a viable means of providing international support. However, mobile measurement teams would be faced with a number of challenges when removed from the resources of the host country. Further, high contamination levels can also lead to special challenges. To strengthen the Nordic capability to conduct mobile measurement strategies under realistic challenging conditions, the newly started MOBELRAD activity will provide an exercise opportunity in the provision of mobile measurement support to a third country following a contaminating event. This will enable participating Nordic organisations to test their equipment, technical and logistical capacities and personnel skills in making measurements in an environment with high contamination levels. The practical part of the activity is planned to be executed in the

Belarussian exclusion zone contaminated by the Chernobyl accident.

### MUD

The MUD activity examines the uncertainties of atmospheric dispersion model predictions due to meteorological uncertainties, and investigates how these could best be presented to decision makers. Hypothetical releases have been modelled from four nuclear power plants, either in or close to Nordic territory. The releases generally involve emissions over a period of 6 hours of the radionuclides Cs-134, I-131, Xe-135 and Pu-239. Four different meteorological scenarios with full forecast series of 54 hours have been defined. The Danish atmospheric dispersion model DERMA and the Norwegian atmospheric dispersion model EMEP have been run for each release scenario from the nuclear power plants and each of the four meteorological scenarios, each involving 25 ensemble members of the DMI meteorological ensemble prediction systems. The dispersion model results have in some cases been found to vary considerably across the ensemble.

### FAUNA

The newly started FAUNA activity builds on the lessons learned and ensemble statistical methodologies developed in the MUD activity, by applying these to the Fukushima Daiichi nuclear power plant accident scenario. The activity addresses real-time forecasting of atmospheric dispersion and deposition of radionuclides released from a nuclear power plant considering the associated meteorological uncertainties. The MUD activity demonstrated that these uncertainties may under some weather conditions be considerable, leading to large uncertainties in dispersion modelling results. The FAUNA activity will carry out investigations of the meteorological uncertainties on real-time assessments of geographical areas affected by radioactivity from the Fukushima accident. The predictions will be made available to the ARGOS decision support system for illustration and dose modelling.

### NORCON

The NORCON activity, which ran in 2014, highlighted the Nordic capabilities for assessment of dispersion and migration of radioactive



contamination after a nuclear power plant accident in the Nordic region, and the associated long term consequences to humans, the environment and society. The participating organisations conducted assessments based on a common source term (primarily a hypothetical release from the Ringhals facility in Sweden) and conditions that would be considered realistic if an accident occurred in a Nordic country. Each participating country on the basis of their own scenario modelling made an assessment of the situation in-line with what would be done in case of a severe accident. Methods of assessment, outputs and the implications for the associated decision making process were examined and compared, enhancing the understanding of how the Nordic countries respond to nuclear accidents, both individually and on the regional level.

#### **PUBPLUME**

This activity addresses the question of how to communicate results of atmospheric dispersion modelling of radioactive contaminants to the public. Following the Fukushima accident there was a considerable demand from media as well as from other Nordic authorities for information showing the dispersion of the release. The question was which products would serve the purpose best, and how to format the information. This activity brings together experts on emergency response, atmospheric dispersion modelling and public communication with the goal of jointly issuing Nordic recommendations on how to produce and present different dispersion products to the public. If such recommendations are adopted, it should be faster and easier to publish dispersion products, and the quality of the information given can be optimized. Factors to be taken into account include relevant types of accidents and incidents, target groups for the information, timing issues, types of dispersion products to publish, layout and design, and responsibility and quality assurance.

#### **SEMUNARS**

As reflected in the amount of Nordic publications on the topic, there is currently a fruitful collaboration between the Nordic countries in relation to mobile gamma-ray spectrometry. Steps have also been taken in

some Nordic countries to investigate the possibilities of employing unmanned systems in radiological assessments, but so far no joint Nordic activities have been carried out in this context. However, the technological development of unmanned systems has now reached a level of maturity that would allow exploitation in various safety and security related applications. The existing experience needs further dissemination and attention, and it is the objective of the SEMUNARS activity to facilitate this through the arrangement of a seminar on unmanned radiometric systems, which was held in Linköping, Sweden, on 2-3 October 2014. Thematic topics for presentations and discussions include platforms, detectors, air sampling using unmanned systems, envisaged applications/scenarios, methods and strategies, calibration/validation, demonstrations, joint exercises and future Nordic collaboration. Further information on the seminar can be found on the NKS website.

#### **THYROID**

Reliable and rapid quantification of radioiodine uptake in thyroid glands may be needed in different types of emergency scenarios. For instance, following the Fukushima accident, a large fraction of the children in Fukushima Prefecture experienced thyroid exposure to radiation. On the background of such measurements, persons significantly exposed to radioiodine, either through inhalation or ingestion, can be identified, and further measurement needs and needs for medical measures can be planned. In the THYROID activity calibration of thyroid monitoring equipment in the Nordic countries was harmonized. A total of 38 sites in the Nordic region were identified, which have equipment that can be used for thyroid screening for radioiodine contamination. Altogether, 93 instruments were calibrated in the activity. The harmonized calibration effort provides a common Nordic traceability chain, facilitating evaluation of the impact of exposure of large groups and associated risks.

#### **THYROIDSEM**

Following up on the establishment in the THYROID activity of a Nordic regional inventory of measurement capabilities for radioiodine measurement in thyroids, a seminar was held in 2014 to discuss the results and conclusions



of the calibration work carried out in 2013. The focus was on the role of thyroid measurements in preparedness, and the overall goal was to further strengthen dose assessment competences and give recommendations on measurement procedures and instrument requirements. Key speakers and a range of stakeholders received special invitations, and participants were asked to answer a questionnaire, which will form the basis for a discussion of key issues.

### *Measurement Strategies, Technologies and Quality Assurance*

#### CONCORE

On and off shore gas producers are currently main producers of technically enhanced naturally occurring radioactive material (NORM) and associated waste in the Nordic region. The amounts of materials that are categorized as NORM contaminated equipment and waste may to some extent reflect the procedures and measurement techniques applied. Different procedures are currently followed for NORM categorization, e.g., by Nordic operators in the North Sea. Various parameters may affect the measurement accuracy and cause wrong material categorization. The new CONCORE activity aims to develop a common scientifically based Nordic recommendation set for practicable and reliable characterization of NORM contaminated objects. Experimental work in the activity will address challenges in measuring low level radionuclide contents in a matrix with, e.g., varying water content and density.

#### GAMMATEST

Acknowledging a great common need within the Nordic countries for gamma ray spectrometric assessments for various purposes, including emergency preparedness, and due to the sparse common Nordic interaction in earlier years, a NKS seminar on the topic was held in 2009, where gamma analysts could inspire each other and exchange experiences. Due to the great interest and attendance, a follow-up NKS seminar was also arranged the following year. On the recommendation of participants from the seminars it was decided in 2011 to arrange a series of workshops on practical issues in gamma ray spectrometry. The follow-up activity in 2012 included practical exercises on real field

spectra. The GAMMATEST activity that ran in 2013 included expert lectures on Monte Carlo simulations for detector efficiency calculations and calculation of correction factors for, e.g., coincidence summing. In 2013, GAMMATEST also comprised a measurement intercomparison exercise.

#### GAMMAUSER

This activity, which ran in 2014, is the latest in the series of NKS activities dedicated to heightening the standard of gamma spectrometric capabilities in the Nordic countries. Since many young scientists and students attend the Nordic gamma ray spectrometry activities, they also serve as an important resource to maintaining Nordic competence in the future. The format of the 2014 activity was in-line with that in 2013: there were invited speakers on issues for which specific interest has previously been expressed, and intercomparison exercises. The focus in 2014 more closely matched the unique set of challenges that each group of attending users faces (e.g., nuclear power plant analysts, regulatory specialists, radiation emergency experts, academic researchers, industrial application developers). How each group deals with their specific challenges will be instructive for other groups to see. The event took place in the autumn of 2014, and more information is on the NKS website.

#### NOVE

Radioactive and nuclear substances may appear in a number of ways, where they may constitute threats to society. For instance through a malicious dispersion act, large inhabited areas may become contaminated, potentially creating a health risk while also causing considerable disruptive effects on the affected society. Illicit trafficking of radioactive and nuclear materials is thus a societal problem, and not all problematic sources are easily detected. Plutonium can be detected via neutrons generated through spontaneous fission, if neutron detection capability is secured. The NOVE activity, which started in 2013 and continued in 2014, has the objective of comparing conventional and novel techniques for detection of neutrons. Neutron detection capabilities of the participating Nordic authorities have been presented, and measurements have been performed in special



field conditions. The activity thus contributes both in the form of a knowledge transfer platform and through generation of experimental results. In 2014, the focus was on dynamic testing, where sources were automatically moved in a controlled way using a 16 m long remote controlled track. More information is available on the NKS website.

#### RADIOANALYSIS

This workshop, which took place in Denmark in September 2013, focused on measurement of pure beta and particularly pure alpha emitting radionuclides, which are not easily assessed, since they have to be isolated from matrix and interfering radionuclides prior to application of for instance radiochemical analysis methods. To maintain and strengthen the Nordic competence in this context a workshop programme was put together, which contained 3 days of tutored hands-on laboratory practice, as well as 1½ days with lectures given by radioanalytical experts from different research fields, and a ½ day with presentations by young participants. A total of 49 persons participated in the RADIOANALYSIS workshop. Both the book of presentation abstracts (NKS-290), the presentation slides and the final report on the activity (NKS-292) can be found on the NKS website.

#### RAPID-TECH

To save critical time and enable quick sample analysis with high sample throughput, while reducing labour consumption and costs, rapid sample processing techniques, including automation through flow-injection, high performance liquid chromatography and vacuum box on-line detection may be attractive, both in emergency preparedness, environmental monitoring, nuclear plant decommissioning and nuclear/radiological waste management. Although some Nordic laboratories have engaged in the development and optimization of such techniques, the area is still novel and merits further examination. The RAPID-TECH activity, which ran in 2014, was to screen the current needs and problems in this context, and experimental work was carried out to shed new light on developments.

#### STANDMETHOD

Environmental safety of Nordic nuclear installations is a sensitive issue to the public

as well as to responsible authorities. This is reflected in recent additions to environmental consequence surveillance programmes. An example is that a range of radionuclides, which are not easily measured, have been added to routine monitoring procedures for discharges and circulation water (e.g., C-14, Ni-63 and Fe-55). Radiochemical analysis methods currently applied by Nordic industry and research organisations need quality control and validation. An obstacle is the lack of suitable reference materials. The STANDMETHOD activity, aims to establish close collaboration between the Nordic key organisations in validating currently applied methods through intercomparison exercises, and to standardize Nordic analytical techniques for routine analysis. New industrial demands will be identified and new radiochemical analysis techniques will be developed as required.

#### *Radioecological Assessments*

##### BERMUDA

Some Nordic households consume tens of kilogrammes of wild mushrooms and berries each year. The contents in these food items of natural radionuclides were however not well known. Also information on transfer factors of naturally occurring radionuclides from soil to wild mushrooms and berries was sparse. The two-year BERMUDA activity, which was finalized in 2013, carried out a survey of the contents of natural radionuclides in Nordic wild berries and mushrooms, and estimated transfer factors as well as effective doses to populations consuming these produces. Also contents of anthropogenic radionuclides in the samples were examined for reference. The most significant contributions to dose from consumption of mushrooms were found to be from Po-210 and Cs-137. Effective doses from consumption of wild mushrooms and berries were estimated to amount to less than 100 µSv per year.

##### COSEMA

The COSEMA activity, which modelled the potential consequences of severe radioactive releases to Nordic marine environments (the Baltic sea and the North Atlantic ocean), was initiated in 2012 and completed in 2013. A hypothetical source term from a 3000 MWth nuclear reactor accident was defined for the Baltic sea studies. The highest estimated



annual doses from consumption of sea food (from a local area) were found to potentially amount to tens to hundreds of millisieverts. Contributions from Cs-134, Cs-137 and I-131 were estimated to constitute some 96% of this dose. North Atlantic incident consequence analyses involved hypothetical nuclear submarine accidents. Model validation was carried out through comparison of calculation results with available experimental data.

#### EFMARE

This new activity builds on the lessons learned in COSEMA on doses from marine releases, but goes in further detail with features of radioecological assessment and evaluates the environmental sensitivity of the Nordic marine environment. The dispersion of radionuclides in water and sediment and associated doses through consumption of marine food items will be evaluated using three different Nordic models, which will be improved as required through modelling of seasonality, bioaccumulation of radionuclides in marine organisms, and biota movements.

#### NORMIN

Also NORMIN is a new activity started in 2014. It aims to describe situations and practices in relation to Nordic uranium mining and mining generating enhanced concentrations of naturally occurring radioactive materials. It is planned that transfer factors and concentrations of radionuclides in NORM-containing ores and old mining wastes will be assessed in different situations in Nordic countries, and resultant radiation risks will be examined. Experimental radioecological case studies will be conducted at relevant sites in each country participating in the activity. The activity also plans to carry out a literature study of the integration of environmental protection issues in Nordic radiation legislation.

### **NKS-R activities in 2013/2014**

Many of the NKS-R activities which have been funded in 2014 are continuing from 2013. In addition, two new activities are funded. Brief descriptions of the activities are given below under the headings of the six different research areas of NKS-R:

- *Thermal Hydraulics*
- *Severe Accidents and Reactor Physics*

- *Risk Analysis*
- *Organisational Issues and Safety Culture*
- *Plant Life Management and Life Time Extension*
- *Decommissioning*

### *Thermal Hydraulics*

#### ENPOOL

Steam injections into the pressure suppression pool of a boiling water reactor and their effects are studied within this project. Short term dynamic phenomena may cause pressure loads on pool structures and long term thermal transients following the steam injection may influence the pool's pressure suppression capacity, which is why this is an important area of research. Experiments and numerical analyses of steam injections through blowdown pipes into the suppression pool are carried out and the main objective is to develop computational models which can be used to simulate the effects of steam injection. In 2013, the experiments concentrated on the dynamics of the free water surface in a blowdown pipe to provide data on mixing of a thermally stratified pressure suppression pool and on direct contact condensation. The experiments carried out with the test facility provide a representative database for numerical studies and modelling, which are carried out under the ENPOOL activity. This activity started in 2011 and continued in 2014.

#### POOLFIRE

The three year project ended in 2013 and focuses on development and validation of prediction models for pool fires in enclosures using pyrolysis models in a CFD model. Pool fire is one of the major fire accident types in nuclear power plants, together with cable and hydrogen fires. The model can be utilized in risk assessments for nuclear power plants and the final report was published on the NKS website.

### *Severe Accidents and Reactor Physics*

#### ATR

Previous experiments have shown that the fraction of gaseous ruthenium transported through the primary circuit of an experimental setup at VTT was higher than what would be



expected in thermodynamic equilibrium calculations. The focus of the ATR project is to study the impact of aerosols on the transport of ruthenium in the containment air of a BWR. Some of the most radiotoxic elements that may be released from the fuel into the containment's atmosphere during a severe accident are iodine and ruthenium. In 2014, the impact of aerosols on the transport of ruthenium, especially gaseous Ru species, were studied in primary circuit conditions. Different aerosol species (e.g. Ag, CsI and RuO<sub>2</sub>), will be injected to the gas flow together with the volatilized RuO<sub>4</sub>. Thereafter the impact on the transport of ruthenium will be studied. A better understanding of the containment atmosphere composition during a severe accident will lead to improved strategies for reducing the risk of ruthenium release to the environment.

#### DECOSE

Uncertainties in assessment of (i) debris bed properties and coolability, (ii) steam explosion impact in BWRs will be reduced by experimental and analytical studies. The experimental part of the project will investigate key physical phenomena of the debris bed formation and coolability. Experimental data will be validated using simulation tools, leading to more reliable predictions of the debris bed coolability in case of an accident with a severe core damage. An analytical approach will be utilized to improve the prediction of coolability and to assess the uncertainties in modelling of steam explosion impact.

### *Risk Analysis*

#### DIGREL

Practical guidelines for analysis and modelling of digital systems in probabilistic safety assessment (PSA) for nuclear power plants are developed within the DIGREL activity. The activity comprises three interrelated activities. Firstly, a taxonomy for failure modes of digital I&C systems has been developed by a task group of OECD/NEA Working Group RISK. Secondly, in a parallel Nordic activity, a fictive digital I&C PSA-model has been developed for the demonstration and testing of reliability modelling approaches. The third activity has been to develop a method for the quantification of software reliability in the

context of PSA. The interim results of the project have been published annually in NKS report series (NKS-230, NKS-261, NKS-277, and two upcoming reports that covers the achievements of 2013). In 2014, the three activities will be finalized and a guidelines report was prepared for the nuclear industry.

#### DPSA

DPSA stands for deterministic-probabilistic safety analysis methodology. The goals of the project are (i) to develop DPSA modelling approaches for scenarios where timing of the events, including PSA Level 1 and recovery actions, has significant effect on the results, and (ii) to develop methods for improving PSA and DSA using DPSA generated data. The project started in 2013 and is scheduled to run for another three years.

#### L3PSA

The Level 3 Probabilistic Safety Analysis (Level 3 PSA) project is seeking to deepen Nordic understanding about the merits and limitations of probabilistic off-site consequence analysis for nuclear facilities. The project began in 2013, and is entering its second year of a planned three years. The project's first year focused on the development and analysis of an industrial survey about Level 3 PSA, which included several workshops and meetings with Nordic utilities, regulators, and safety experts. Level 3 PSA risk metrics including health, environmental, and economic effects have been researched and discussed in the first year's project report. The project has generated significant interest internationally and has interfaced with international organizations including the IAEA and the American Nuclear Society. The ultimate goal of the project is to produce a guidance document for Level 3 PSA in Nordic countries.

#### EXAM-HRA

Are there actual differences in plant features that explain why human reliability analysis (HRA) results differ between plants for similar action or is this merely a result of differences in the HRA with respect to choice of method, analyst judgment, PSA scope, resources spent, etc? Identifying discrepancies in HRA applications is the first step in finding these answers.



EXAM-HRA is a Nordic, Swiss and German project which assesses HRA applications in existing probabilistic safety analysis (PSA) studies. The overall project objective is to provide guidance for a state of the art HRA for purposes of PSA, to ensure that plant specific properties are properly taken into consideration in the analysis. The project results provide insights to improve the experience feedback on actual plant features based on HRA and PSA results. A summary report is available on the NKS website.

### *Organisational Issues and Safety Culture*

#### **HUMAX**

Maintenance is a key safety function in any complex sociotechnical system, such as a nuclear power plant. The aim of the NKS-R activity HUMAX is to enhance understanding on how to maximize human performance in maintenance activities of nuclear power plants. In 2013, the use of specific tools, or lack thereof, has been analysed for three Nordic nuclear power plants. Interviews have been made with maintenance workers and those responsible for developing human performance programs on their opinions on the human performance tools. The project was finalized in 2014 and reported on in 2015 and the aim is to provide recommendations on how to design and implement effective human performance tools.

#### **ProCom**

Extensive research has been performed by different organisations to identify the functions that enable reliable and resilient procedures. Measuring these functions reliably presents its own set of challenges. These are mainly (i) identifying reliable markers for each competence and (ii) developing guidance so that observers can reliably assess the crew's degree of proficiency on each competence. Institute for Energy Technology, IFE, in Halden has access to a huge amount of data from simulator studies of complex emergency scenarios, that can be used for identifying procedure competence. The activity is a one year project ending in December 2014.

#### **SADE**

A number of design flaws have been contributing to major industrial accidents.

However, design activities are still a fairly understudied subject in human and organisational factors or safety culture studies. The three-year project on safety culture in design has now been finalised. One of the main conclusions of the study was that design-related challenges in the nuclear domain are mainly inter-organisational. Hence, safety management and safety culture approaches should be improved with respect to the inter-organisational nature of the work process in design. The study provides a set of recommendations to the nuclear community to support and improve the design process and to anticipate emerging risks.

### *Plant Life Management and Life Time Extension*

#### **Nordic-Gen4**

The objective of this forum is to promote communication and interaction between Nordic researchers in the generation IV reactor area. The network has existed since 2009. Originally the focus was on material issues, but now the scope is wider. The main activity has been to organise seminars with participants from academia (senior researchers and students) and industry. A two-day seminar in Lappeenranta was held in September 2014, where both invited speakers from Europe and PhD-students had a chance to present and discuss their research. Other activities of the network include smaller meetings, students visits as well as maintaining the website <http://nordic-gen4.org/>

### *Decommissioning*

#### **DECOM-SEM**

A seminar on decommissioning of nuclear facilities was held on 6-7th November 2013 in Halden, Norway. It was arranged by IFE together with ndcon, NRPA, Danish Decommissioning and Fortum. The seminar provided an opportunity to meet and exchange experiences from completed and on-going decommissioning projects as well as discuss the future. There were 36 participants, from the Nordic countries, representing almost every branch in decommissioning, including operators and regulators. Three topical sessions covered issues related to:

1. Decommissioning and dismantling of nuclear facilities



2. Release of materials, facilities and soil (site)
3. Management and final disposal of waste from decommissioning projects

In total 16 presentations were given in addition to round table discussions. The presentations and proceedings are available at <http://projects.hrp.no/nks-decom-2013/>

## Conclusion

Summarised information has been provided on the objectives, plans and findings to date for each NKS-R and NKS-B activity that ran in 2013 or/and in 2014. The diversity in research topics is considerable, and even activities grouped under the same overall research type category often deal with very different topics and societal challenges. The paper illustrates the current trends and needs in Nordic nuclear and radiological safety and preparedness planning, and demonstrates that new ideas thrive in a region where cross-border collaboration has been nourished over decades on a joint platform.

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